Office of ELECTRIC TRANSMISSION & DISTRIBUTION
U.S. Department of Energy

NREL

Interconnection Testing at NREL

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Electric Distribution Transformation Program

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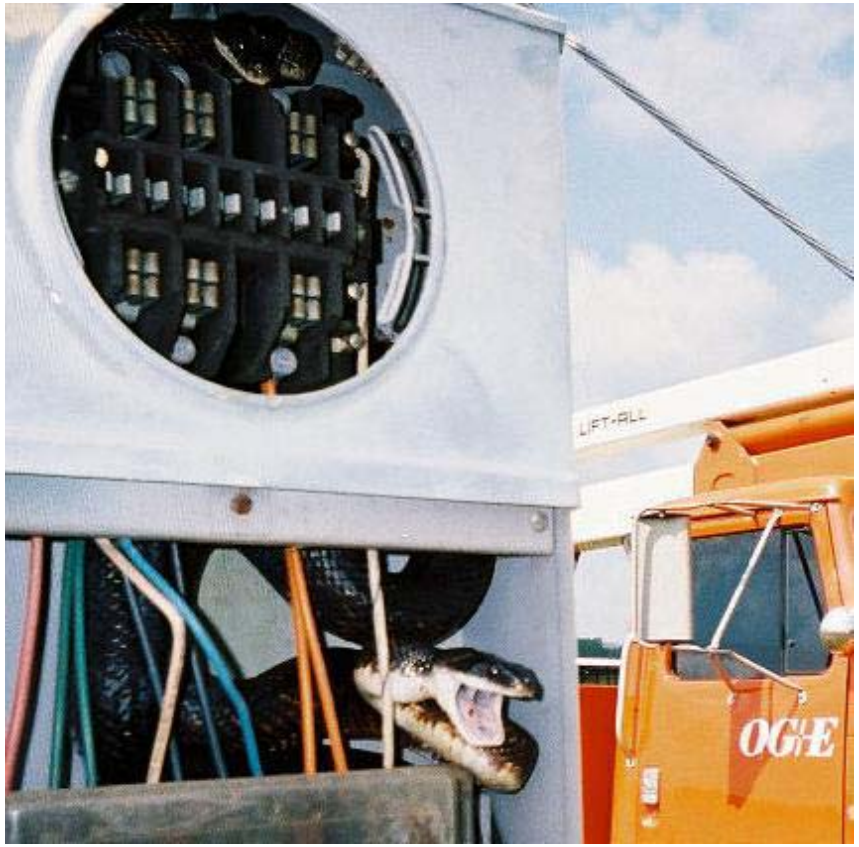
Relevance to Problems & Needs

The *National Electric Technologies Roadmap* stated several important needs in the local distribution area:

- **Testing of advanced hardware of interconnection and control** of distributed resources and **simulation and modeling** of distribution systems and end-use for operations of the electrical system.
- Need to develop facilities for manufacturers of interconnection and control technologies to **test prototype equipment** using actual distributed generation and storage technologies.
- Need to "develop a distributed resources end-use integration network" with engineering solutions and demonstrations of **microgrids and networked DR**.
- **Develop accurate models** that analyze the impacts of integrating distributed resources with the electric power system are critical to understanding integration issues and for providing solutions.
- Advanced models are needed to increase understanding toward more effective operations, better testing, and, to contribute to improved device and system architecture and design.

Technical Challenges of Current Practices

The *National Electric Technologies Roadmap* listed the following high priority **technical challenges** that this activity addresses:



One of the Challenges to Interconnection

- Design of an acceptable "black box" for DG interconnection and lack of low cost, reliable interconnection devices for DR
- Understanding the interoperability of devices on distribution systems
- Understanding the impact of DG on networked distribution systems
- Accurate models that analyze the impacts of integrating distributed resources with the electric power system are critical to understanding integration issues and for providing solutions.

Project Objectives

- **Systems Characterization, Distribution Impacts, and Operational Field Testing**
  - Test and demonstrate advanced technologies for interconnection, integration, and control of distributed resources and test advanced operating concepts for distribution systems. Validation of interconnection testing and communications standards.
- **Distribution Systems Impacts and Modeling**
  - Studying concepts and impacts, and developing modeling and analysis tools to support detailed analyses of complex interactions of distribution systems, distributed resources including generation, storage and load control, and, protection and coordination devices.

Technical Approach

- **Interconnection System Characterization**
  - **Prototype testing for manufacturers of interconnection systems**
- **Test Procedure Validation**
  - **IEEE 1547, IEEE 1547.1, UL 1741**
- **Advanced Distribution System Operational Concepts**
  - **Intentional Islanding (Microgrids), Hybrid Systems, Distribution Networks**
- **Distribution Systems Impacts and Modeling**
  - **Modeling and Simulation of DR impacts on distribution and transmission systems**

Technical Approach – NREL DER Test Facility

3 AC Buses

Utility Grid

Wind Turbines

Inverters

3 DC
Buses

Electrolyzer

Technical Approach – Interconnection System Characterization

Distributed Energy Resources


Fuel Cell


PV


Microturbine


Wind


Energy Storage


Generator

Interconnection Technologies

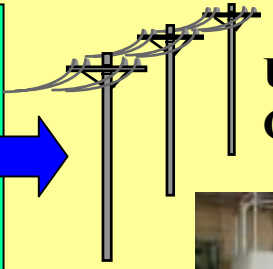

Inverter

Functions

- Power Conversion
- Power Conditioning (PQ)
- Protection
- DER and Load Control
- Ancillary Services
- Communications
- Metering


Switchgear, Relays, & Controls

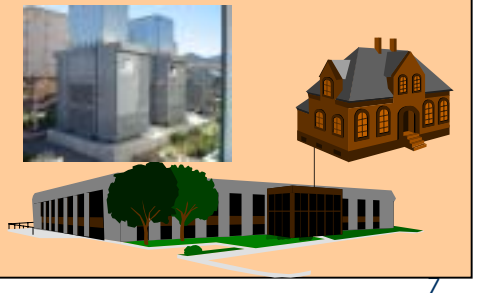
Electric Power Systems


Utility Grid


Utility Grid Simulator
Micro Grids

Loads

Local Loads
Load Simulators

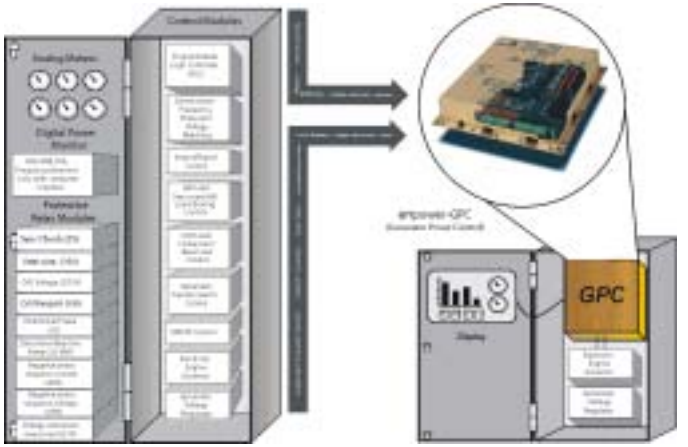


Technical Approach – Interconnection System Characterization

- NREL conducts testing that includes characterization and evaluation of prototype distributed power system technology for interconnection, control, and aggregation with electric power systems.

GE Universal Interconnect

- NREL has been working with GE and ENCORP on the development of advanced interconnection systems for DR. NREL completed testing of a prototype Universal Interconnection Device from GE. A 125kW synchronous generator was used with the GE UI.



ENCORP GPC Controller

Technical Approach – Test Procedure Validation

- NREL also conducts testing for the development and validation of test procedures. This activity includes working with IEEE and UL. The focus on FY03 testing was to conduct testing on inverter (Capstone) and non-inverter (ASCO) based DR interconnection equipment.

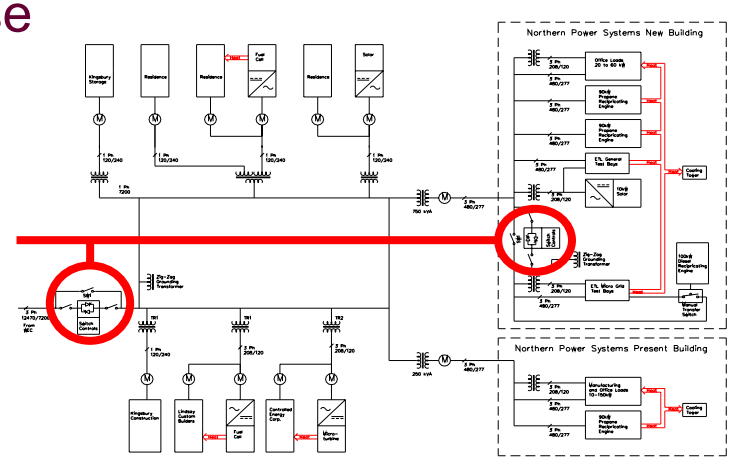
- The tests that were conducted included validation of tests from IEEE P1547.1 "Standard for Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems". These include tests for response to abnormal conditions (i.e. over/under voltage and frequency, loss of synchronism, disconnection for faults) and power quality (i.e. limits for DC injection, harmonics, surge capability).

ASCO Soft-Load Transfer Switch

Capstone Microturbine

Technical Approach – Advanced Distribution System Operational Concepts

- NREL evaluates advanced operational concepts to improve distribution system reliability. These include intentional islands (Microgrids), networked distribution system, and DR aggregation with electric power systems.



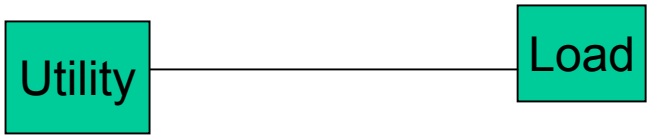
- In FY03 a multi-DR test container was constructer to allow for the testing of multiple DG on a single feeder. The focus on FY04 testing will to examine issues and develop recommendations for the development of *IEEE P1547.4 "Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems".*

- Collaborative testing will be conducted on various types of distributed generation (PV, wind, fuel cells, generators, micro-turbines, energy storage, etc.) for interconnection and system aggregation issues.

Technical Approach – Advanced Distribution System Operational Concepts

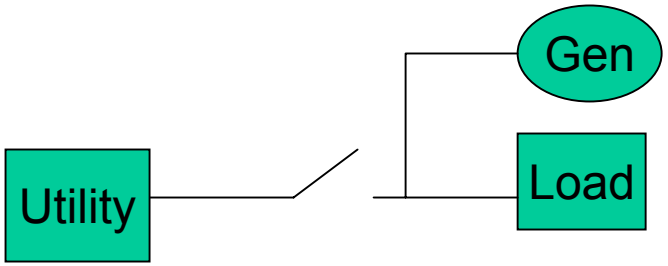
•Radial Distribution System –

•The most common type of connection between utility and load. Power only flows from utility to load.



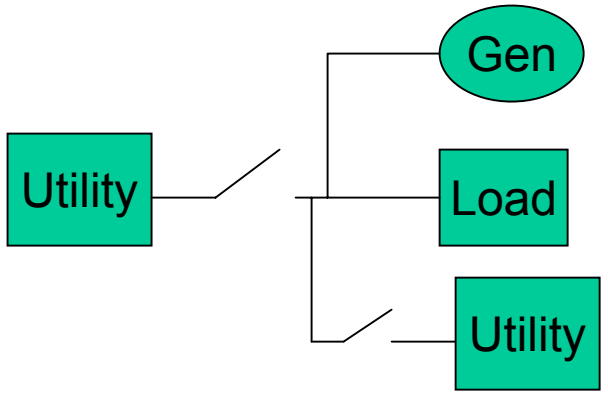
•Intentional Island (Microgrid)-

Aggregation of loads and sources capable of operating either in parallel with or independent from a larger electric grid, while providing continuous power to end users. Depending on configuration, power flows only within microgrid or can export power to utility.

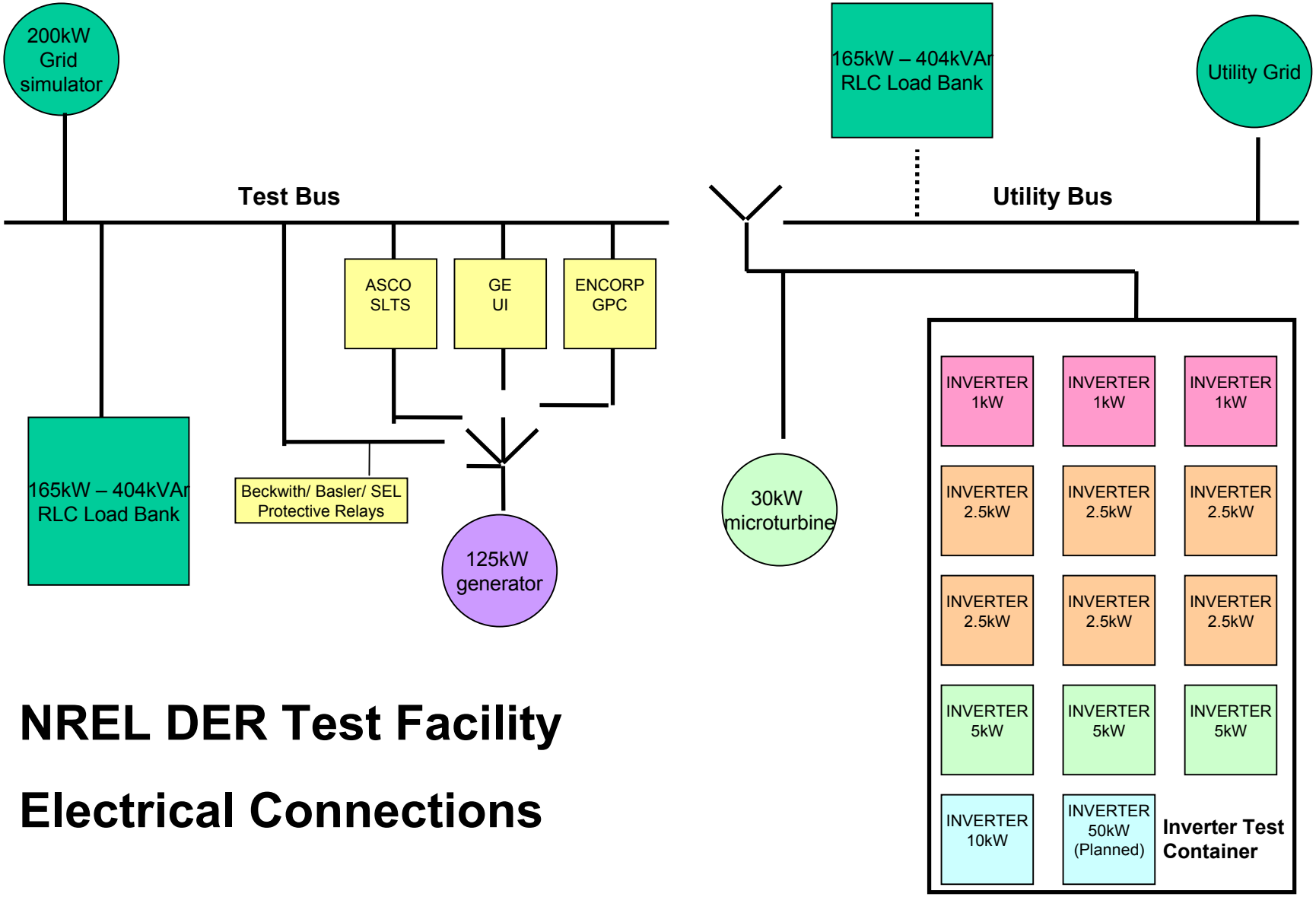


•Networked Distribution System w/ 2-way power flow -

Distribution in which the secondaries of the distribution transformers are connected in a grid, typically energized at the customers' utilization voltage, to serve multiple loads.



Technical Approach – Advanced Distribution System Operational Concepts



NREL DER Test Facility

Electrical Connections

Technical Approach – Testing Subcontracts

- **University of Wisconsin** is developing control software to achieve a synergistic combination of efficient electrical energy generation sources and delivery of high quality premium power for critical loads. The work will enable distributed generation systems to deliver high quality power as well as provision of energy needs.

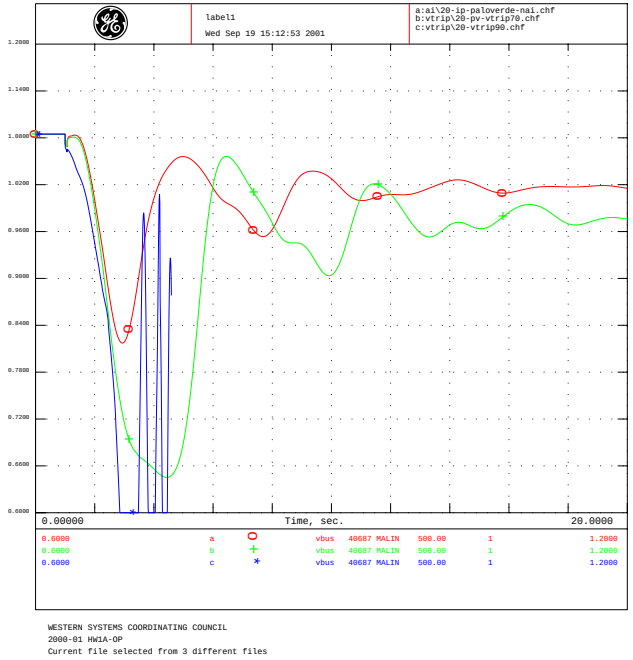
- Cooperative Research Network of the **National Rural Electric Cooperative Association** (NRECA) is helping rural cooperatives, assess, select, install in residential locations, and test and evaluate residential fuel cells, as an example of distributed power applications, to enhance service reliability, improve energy supply, and minimize costs to managing load growth.

- **Distributed Utility Associates (DUA)** - The Distributed Utility Integration Test (DUIT) Project is to be a thorough test of the issues raised and value of co-location and integration of diverse distributed generation and storage technologies into the electric distribution system. The units will be instrumented to measure the potential electric distribution system advantages and challenges of substantial penetration (approaching 80% of local load) of distributed generation and storage at distribution voltage levels. The project will focus on the identification of issues, and measurement and analysis of the interactions between units and the distribution system rather than the operation of any single innovative distributed generation technology and storage component.

Technical Approach – Modeling Subcontracts

General Electric — Development of Commercially Available Interconnection Devices Meeting the Requirements of the P1547 Standard

GE has been modeling the effect of integrating distributed resources with the electric power system. GE has studied and developed Anti-Islanding algorithms for three-phase inverter-based DG. Commercial software Saber is be used to model power electronic inverters. Commercial software PSCAD will be used to model machine-based DGs. GE has also developed a tool set that allows for the simulation of significant levels of penetration levels using one of the utility industry standard simulation packages, PSLF. This tool can handle large-scale power systems problems-system models with thousands of generators; and tens of thousands of buses, loads, and circuit elements are commonly used.

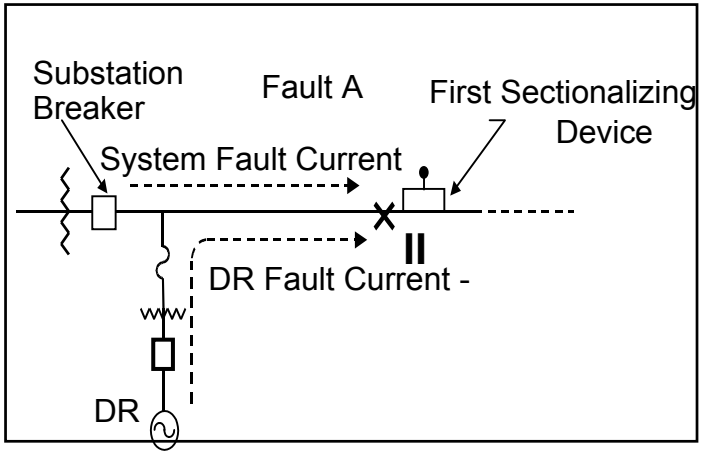


DTE Energy - Investigation of Electrical Systems Issues Related to Increased DER Penetration

Based on the "29 issues" report published by EEI, DTE Energy conducted a study of distributed resources interconnected with the utility grid. Results provided simplified guidelines and modeling techniques and simulation/modeling to define the penetration limits of DR on two distribution feeders. Two utility grid distribution feeders were modeled and impacts assessed on the installation of distributed power systems at selected customer sites/feeders.

University of Wisconsin at Madison — Hardware Demonstration of the Feasibility and Value of Distributed Resources

The Univ. of Wisconsin is focused on various aspects to study the steady state and dynamic interactions occurring in a microgrid consisting of various distributed generation systems. The models are constantly being refined using a laboratory scale microgrid to improve their accuracy.



Technical Approach – Systems Interconnection Test Laboratory

- Completed Design in FY02

- Construction was delayed to FY04 because of funding reductions

- Increase testing capability to 1MW total system size

- Focused on development and validation of interconnection standard testing methods and procedures

- Testing system integration, configurations (Hybrid, stand-alone, grid-connected), and aggregation.

FY03 Progress and Accomplishments

- Completed Testing of ASCO SLTS (Synchronous Generator Based Interconnection Technology) – Completion of testing started at Nevada Test Site.
- Completed Testing of Prototype GE Universal Interconnect Device – Working with GE to develop next generation interconnection device
- Completed Hardware Installation of Multi-DR Test Container – planned capability for testing impact of multiple DR on single feeder and advanced operational concepts
- Completed GE Modeling Report – examined impact of DR on electric power system
- Completed DTE Modeling Report – examined impact of DR on coordination, fuse blowing, faults, harmonics, voltage regulation, and transient and steady-state stability.

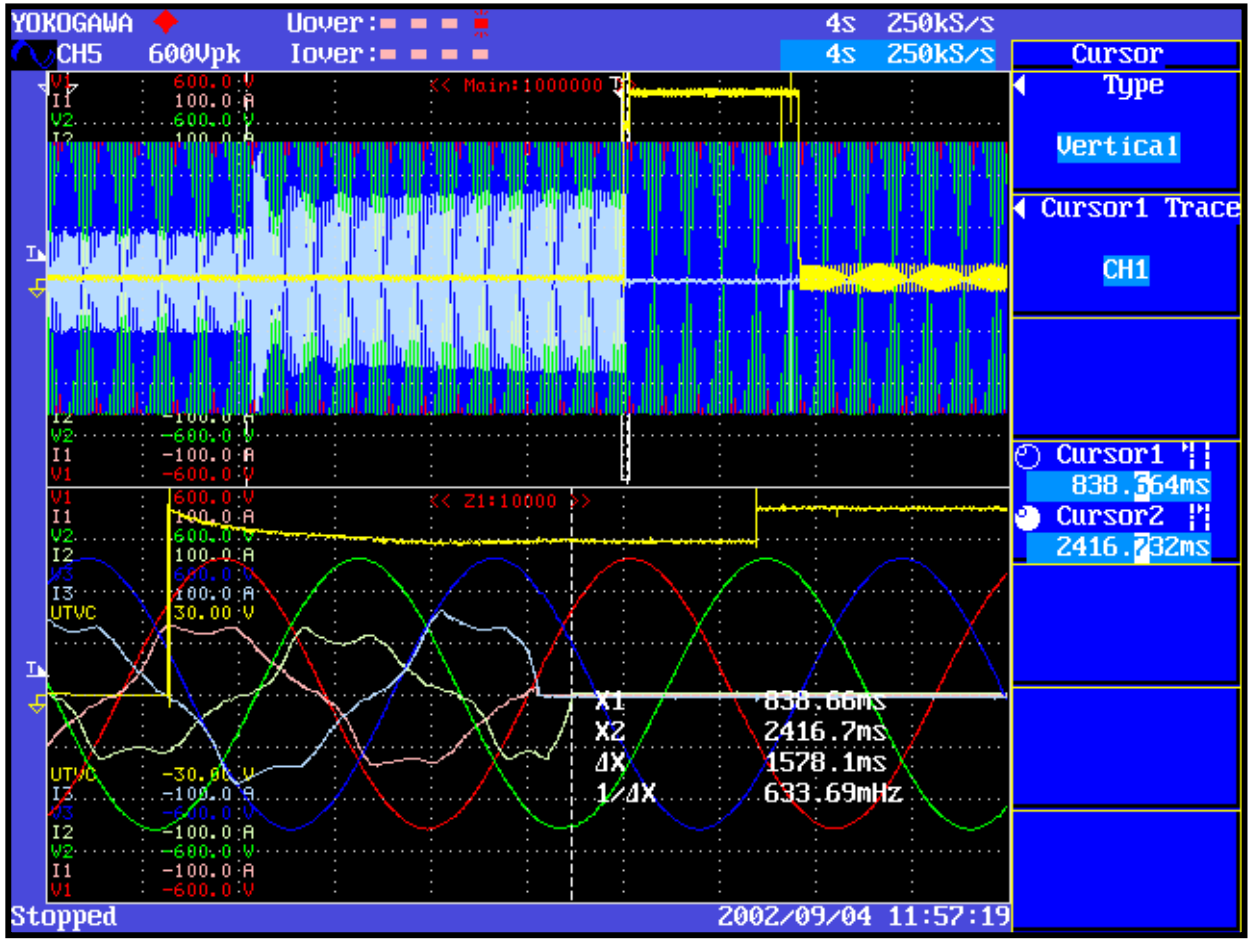
FY03 Progress and Accomplishments -Publications

- Systems Characterization, Distribution Impacts, and Operational Field Testing
  - *"Testing of GE Universal Interconnection Device",* NREL/TP-560-34676, August 2003
  - *"Validation of IEEE P1547.1 Interconnection Test Procedures: ASCO 7000 Soft Load Transfer System",* NREL/TP-560-34870, September 2003
  - *"DUIT: Distributed Utility Integration Test",* NREL/SR-560-34389, August 2003

- Distribution Systems Impacts and Modeling
  - *"Report on Distributed Generation Penetration Study*", NREL/SR-560-34715, August 2003
  - *"Distributed and Electric Power System Aggregation Model and Field Configuration Equivalency Validation Testing"* NREL/SR-560-33909, July 2003
  - *"Hardware Development of Laboratory Scale Microgrid – Phase II - "Operation and Control of a Two-Inverter Microgrid",* NREL/TP-NREL/SR-560-35059, November 2003

FY03 Progress and Accomplishments

- Testing Results from ASCO SLTS – Underfrequency Time Test



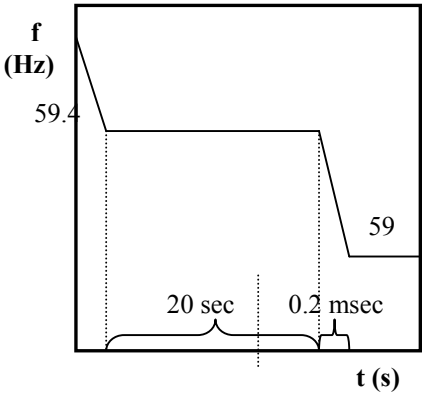
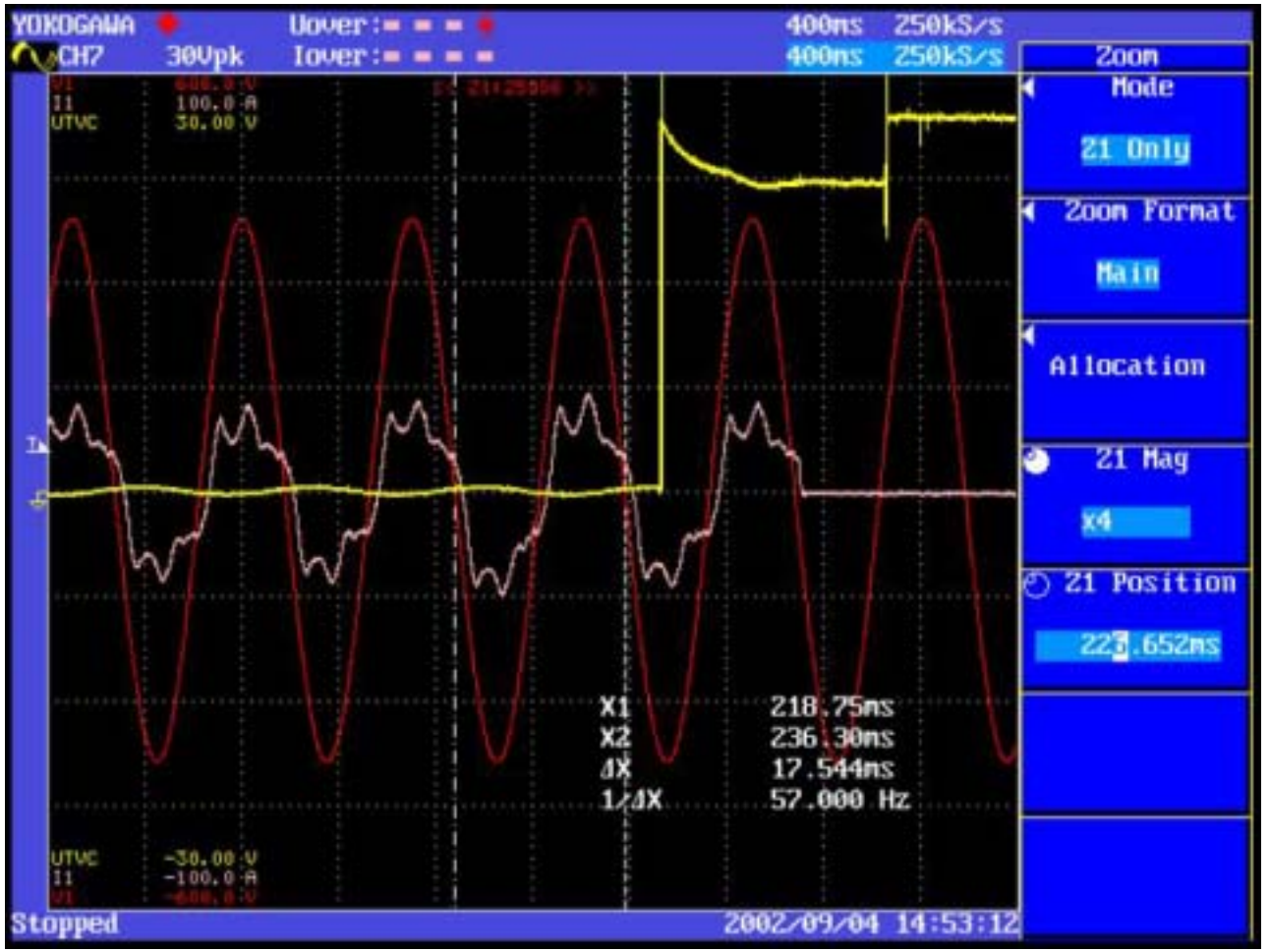


Table 1. Underfrequency Time

Underfrequency Time	
Trial Number	Trip Time (s)
1	1.58
2	1.48
3	1.58
4	1.57
5	1.54
Average	**1.55**
Required	**1.70**

FY03 Progress and Accomplishments

- Testing Results from ASCO SLTS – Underfrequency Magnitude Test



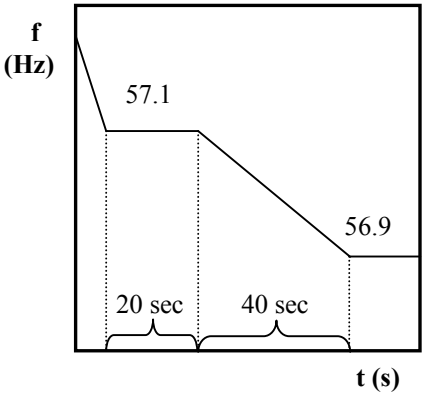
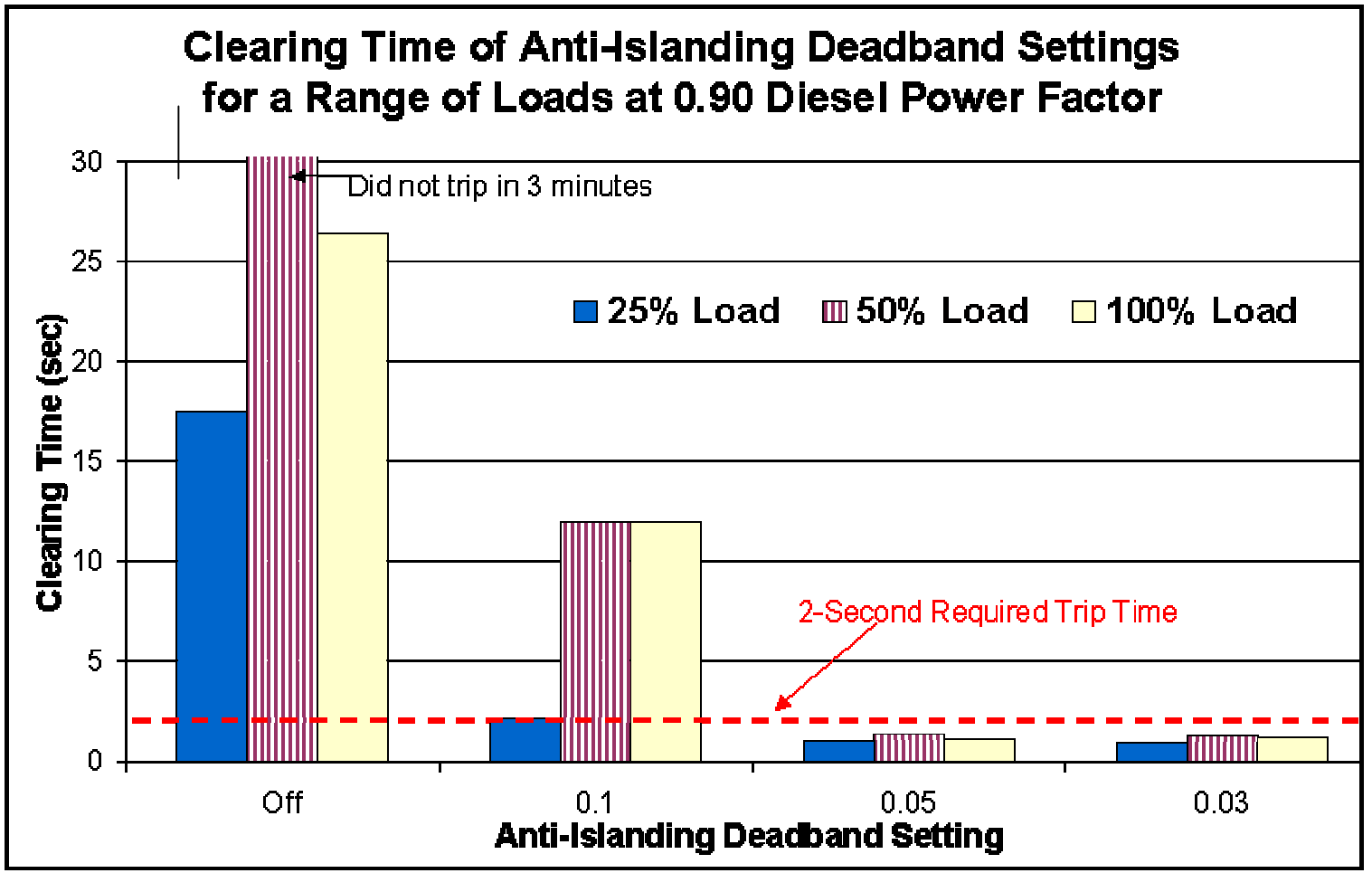


Table 1. Fast Underfrequency Magnitude

Fast Underfrequency Magnitude	
Trial Number	Trip Frequency
1	57.000
2	56.987
3	57.000
4	57.000
5	56.987
Average	**56.995**
Setting	**57.0**

FY03 Progress and Accomplishments

- Testing Results from ASCO SLTS – Islanding Test



Planned Activities for FY04

- Extend Interconnection System Characterization with updated prototypes from ENCORP, GE, and Northern Power.
- Complete the development and validation of tests for IEEE P1547.1
- Expand collaborative testing on various types of distributed resource interconnections (inverter and non-inverter) for interconnection and system aggregation issues.
- Conduct Intentional Islanding (microgrid) component and system testing and examine issues with interconnection of multiple DGs.
- Continue model and simulation development work with GE. Univ. of Wisc. and DUIT.
- Hold a Technical Workshop on Distribution System Modeling

Summary of Outyear Activities

- Outyear testing activities will include continued testing of hardware for interconnection and control of DR at the NREL Test Facility and continued funding of demonstration projects that contribute to the understanding of DR integration issues (penetration limits, islanding, use of DR on microgrids and networks).

- Outyear modeling work will examine the planned modeling workshop's outcome. For this a solicitation for will be conducted for modeling work that examines the impact of DG to solve technical issues and show economic and reliability benefit to the distribution and transmission system.

Life-Cycle Project Timeline

- In-House FY04 Milestones
  - Conduct Hardware Characterization on GE UI and ENCORP controller
  - Conduct exploratory testing on impacts of multiple DR on single feeder
  - Conduct a Technical Workshop on modeling
  - Develop targeted solicitation on distribution modeling
- Budgets

Systems Characterization, Distribution Impacts, and Operational Field Testing

	FY03 ($K)	FY04 ($K)	FY05 ($K)	FY06 ($K)	FY07 ($K)
In-House	689	490	614	753	828
Subcontracts	296	462	650	715	787
Systems Inter. Test Lab	0*	1,500	3,000	1,000	500

Distribution Systems Impacts and Modeling

*1.5M deferred to FY04

	FY03 ($K)	FY04 ($K)	FY05 ($K)	FY06 ($K)	FY07 ($K)
In-House	114	108	133	146	161
Subcontract	101	100	500	550	605

Impacts and Benefits

- This project provides benefits to manufacturers of DR interconnection and control hardware by providing a laboratory that has the flexibility of multiple DG, storage devices, and loads for characterizing the performance of their equipment.
- This project also provides a benefit to utilities and other potential customers of DR by providing a demonstration of multiple types of advanced operating concepts for integrating DR into distribution systems.
- The models and analyses will benefit the development, acceptance and implementation of new architectures, systems, components, and operational concepts.
- These benefits will be seen as more affordable interconnections and improved reliability from the implementation of DR and advanced distribution system operation concepts.

Interactions & Collaborations

- **Interconnection System Characterization**
  - GE
  - ENCORP
  - Northern Power
  - ASCO Power Technologies
  - Capstone Microturbine
  - Xantrex
- **Test Procedure Validation**
  - IEEE
  - UL
  - GTI
  - SRI
  - ASCERTTI
  - EPRI-PEAC

ASCO Power Technologies

ENCORP

Capstone

xantrex

IEEE Standards Association

UL Working for a safer world

Southern Research Institute
Affiliated with the University of Alabama at Birmingham

gti

EPRI PEAC

ASERTTI

Interactions & Collaborations

- **Advanced Distribution System Operational Concepts**
  - Northern Power Systems
  - DUIA – DUIT
  - PG&E – DUIT
  - California Energy Commission

- **Distribution Systems Impacts and Modeling**
  - General Electric
  - University of Wisconsin
  - DTE Energy

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